

## **DESCRIPTION OF ALTERNATIVE NAVIGATION ARCHITECTURES**

### **1. Introduction**

#### **Background**

Beginning in the early 1990s, the Federal Aviation Administration (FAA), in response to and in collaboration with airspace users, developed a strategic initiative to transition to a satellite-based navigation system. Satellite navigation (SATNAV) service using the current Global Positioning System (GPS) is now available, with some restrictions, for oceanic, en route, terminal area, and nonprecision approach operations, and as an aid to navigation under Visual Flight Rules (VFR). The FAA developed a plan to transition to a robust SATNAV system that will provide en route, terminal area, nonprecision approach and precision approach throughout the National Airspace System (NAS), including approaches with vertical guidance to all instrument runways. As originally planned, the SATNAV capability would be robust enough to permit the eventual decommissioning of most conventional ground-based navigational aids (NAVAIDs) and associated avionics, resulting in significant potential savings for the FAA and users.

However, recent concerns about the high cost of acquiring Geosynchronous Satellites (GEOs) and the vulnerabilities of GPS (particularly to interference with GPS signals) have led the FAA to reexamine available navigation alternatives. This examination will include a review of a broad range of navigation options, including Satellite Navigation (SATNAV), ground based navigational aids (NAVAIDs), and user avionics capabilities. The plan for the examination is described in the FAA's "Satellite Navigation Investment Analysis Plan," (December 14, 1998).

#### **Navigation Services**

##### *Current Navigation Services*

The FAA has the responsibility for air navigation service in the US. The radio aids to navigation currently operated by the FAA generally provide point-to-point navigation and include Very-high frequency Omni Range (VOR), Distance Measuring Equipment (DME), Non Directional Beacons (NDBs), Instrument Landing Systems (ILSs), and other navigation and landing aids for civil aviation. The FAA also operates certain Tactical Air Navigation (TACAN) elements for military users. These systems support a ground station to ground station route structure.

In addition to navigation services provided by the FAA, the US Coast Guard operates the Loran C system, which is available for en route IFR navigation. Finally, the Department of Defense operates GPS, which is also available to civilian users for oceanic, en route, terminal area, and nonprecision approach navigation. These systems support a direct route navigation service.

### *Future Services*

The future Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) concepts are predicated on a global and reliable area navigation (RNAV) capability. To enhance safety, the FAA has specified a goal of developing instrument approaches with vertical guidance to all instrument runways. To augment GPS and provide this capability, the FAA has begun development of a Wide Area Augmentation System (WAAS), where ground stations distributed throughout the NAS receive signals from GPS satellites, and transmit information from these signals to master stations. WAAS monitors each GPS satellite in view to ensure that the satellite is transmitting a correct signal and to estimate satellite clock errors, orbital errors, and, in some alternatives, ionospheric errors. This information is then transmitted to the user via GEOs. The WAAS program is intended to provide a more robust satellite navigation service to improve safety by making available precision-approach capability to most runways, to provide affordable RNAV to most aircraft, and to allow the eventual decommissioning of many conventional ground based NAVAIDs. These changes can result in significant cost savings for the government and for users.

The FAA is also developing a Local Area Augmentation System (LAAS), which also uses ground stations to monitor the GPS satellites, but provides corrections to the user via a local datalink transmission. A LAAS system could provide precision approach capabilities through Category III, curved approaches, and surface navigation under all weather conditions.

The first phase of the FAA's WAAS system is nearing completion and will reach Initial Operational Capability in 2000. LAAS systems are currently under development.

### **Assumptions**

Some key assumptions in developing the alternatives are:

- A unique navigation solution is not necessary for all users or all classes of users.
- The study considers only aviation users in US airspace.
- Inertial reference equipment will continue for transport jets.
- Surveillance in congested airspace will continue to be provided by a sensor independent of navigation.
- Loran C will be available at least through 2008.
- GPS accuracy degradation (Selective Availability (SA)) will be turned off by 2006, and a second GPS frequency will not be operational for civil aviation before 2015.
- Approaches with vertical navigation will be developed for all IFR runways where obstacles and airspace permit.
- Satellite service similar to the current Inmarsat 3 capability for augmenting GPS performance will continue to be available beyond the expected Inmarsat service life.

- The GPS constellation will be maintained with improved satellite reliability and launch policies that anticipate or quickly respond to GPS satellite failures.

## ***2. Approach to Developing Alternative Navigation Architectures***

To develop alternative navigation architectures, it is necessary to consider the operations of each major group of airspace users and applicable navigation technologies for every phase of flight. Combinations of technologies that would not provide service for every phase of flight, or which would exclude particular user groups, have not been pursued (e.g., a Loran C-only operation). Some newer technologies that would require development were not included in the alternatives, but may be pursued in later studies after a better understanding of their feasibility and operational concepts are known. It is possible that a small number of US airports will find MLS and other technologies advantageous; we assumed that these "niche" applications will not significantly impact the overall evaluation. Finally, we believe that, subject to further review, all of the candidate architectures can meet FAA requirements.

Our intent is to focus on decisions that must be made in the near term, especially the WAAS architecture. Thus, we defined four major alternatives which span the investment alternatives for the WAAS structure. Each alternative is a combination of satellite-based and ground-based modules, with each module providing specific levels of service at an associated cost. In the following sections, each of the modules is first described; then four alternatives composed of various modules are discussed.

The descriptions of the four alternative navigation architectures are presented from three perspectives:

- Navigation services provided by the FAA
- Operational capabilities
- Associated user equipage

During the development phase, these alternatives are being discussed with the FAA, users and industry. Once the alternative architectures are fully defined, an analysis will be conducted to determine relative levels of cost, benefits, and risks.<sup>1</sup>

## ***3. Description of Navigation Modules***

---

<sup>1</sup> FAA requirements will be met by each navigation alternative, but may not be met by only GPS or augmented GPS. For example, the current .99999 availability for requirement for the WAAS program may be met by a combination of reduced WAAS and retention of VOR/DME for redundant navigation.

## Wide Area Augmentation Systems

### No WAAS

This module uses GPS without wide area augmentation, providing essentially the same services and capabilities as currently provided, except that Instrument Procedures with Vertical guidance (IPVs)<sup>2</sup> would be developed to all instrument runways, terrain, obstacles and airspace permitting. Receivers would use RAIM<sup>3</sup> for integrity monitoring. The IPVs would be based on Barometric Vertical Navigation (BARO VNAV). The average long-term time the unaugmented GPS system would not be available is approximately 5 percent, or about 400 total hours per year. Implementation of this alternative will require removal of WAAS Phase 1 assets.

### Simplified WAAS (No Precision Approach)

This module provides en route RNAV through nonprecision approach service with high availability; the total average outage time should be less than approximately one hour per year (when at least one visible GEO remains available). Simplified WAAS (No Precision Approach) would also include IPVs (supported by BARO VNAV), but would not be suitable as an only means of navigation for scheduled airlines or for busy airspace. Addition of another Instrument Flight Rules (IFR) navigation source, such as VOR or DME, would be required for busy airspace and airports. No satellite-based precision approach service will be provided by this system.

This module augments the GPS with a WAAS system to monitor integrity, and contains several GEOs to provide a broadcast of wide-area integrity and clock/ephemeris information and a GPS-like ranging signal to users. (The tentative composition of this WAAS system is 2 Inmarsat GEOs, probably 1 additional GEO, and approximately 13 WAAS Reference Stations (WRSSs), plus communications to support the system.) The additional GEO ensures that there is no single point of failure for the WAAS system. Implementation of this system will require that some WAAS Phase 1 assets be removed.

---

<sup>2</sup> An IPV is an instrument approach procedure with vertical guidance, but to higher minima than for a Category I precision approach. An IPV will use either airborne barometric altitude (BARO VNAV) or augmented GPS for vertical guidance. BARO VNAV generally requires improved altitude encoding, via a digital altimeter, an air data computer, or an improved altitude encoder. Also, the approach capability will have to be included in the GPS avionics.

<sup>3</sup> Receiver Autonomous Integrity Monitoring (RAIM) is an algorithm in user receivers to verify the integrity of GPS satellite signals by comparing position solutions computed from extra GPS satellites.

### Simplified WAAS (With Precision Approach)

This module would provide similar RNAV en route through nonprecision approach service as the previous WAAS module—with an average total outage duration of less than approximately one hour per year. In this module, however, IPV approaches would be included using GPS vertical guidance (rather than BARO VNAV guidance), plus Category I precision approach service. The system would not provide the IPV or precision approach capability everywhere with high availability, such as in some coastal regions, nor meet requirements to be an only means of navigation for scheduled airlines or for busy airspace.

This module augments GPS with a more capable WAAS system to both monitor integrity, provide wide area differential corrections, and to provide GPS-like ranging signal to users. The tentative composition of the WAAS system is 2 Inmarsat GEOs, 1 additional GEO (possibly with dual frequency), and approximately 25 WRS in CONUS, 8 WRSs in Canada, 3 WRSs in Mexico, plus communications to support the system. Improvements in ionospheric modeling may allow a reduction in the number of WRSs or improvements in precision approach or IPV availability.

### Full WAAS

This module will provide en route through precision approach service with better availability than Simplified WAAS (With Precision Approach), and also will support IPV with high availability. This module offers the most promise for reducing avionics requirements and for reducing the numbers of ground-based NAVAIDs.

This module augments GPS with a much more robust WAAS system to provide en route through Category I Precision Approach services throughout the NAS with high availability. The tentative composition of the WAAS system is 2 Inmarsat GEOs, one or more additional GEOs (possibly dual frequency), approximately 58 WRS in CONUS, Canada, and Mexico, plus more robust communications, operational, software, and security improvements to support the system. Improvements in ionospheric modeling may allow a reduction in the number of WRSs or improvements in precision approach or IPV availability.

### LAAS and ELAAS

LAAS will provide users with Category I precision approaches with very high availability, and, depending on the installation and airport, Category II/III precision approaches with very high availability.

Four levels of LAAS are analyzed in the alternatives:

- No LAAS
- LAAS for alternatives that do not provide full WAAS Category I precision approaches, i.e., the “No WAAS”, “Simplified WAAS (No Precision Approach),” and the Simplified WAAS (With Precision Approach) alternatives. This consists of as many as 650 (plus growth) Category I/II/III LAAS units.
- LAAS to augment the alternatives that provide precision approach, i.e., “Full WAAS” This consists of ~143 Category I/II/III LAAS units.
- A possible extension of the LAAS system, Extended LAAS or ELAAS, would increase the power of LAAS stations and provide GPS integrity and correction information to en route aircraft, in addition to the normal terminal capabilities.

## **VOR and DME**

Three levels of VOR and DME are considered in various alternatives. The first level is the current system, including projected growth over the study period. The second level is the Minimum Operational Network, as defined by the FAA, that includes approximately 614 VOR/DMEs (552 in CONUS). These VOR/DMEs were selected to provide coverage along routes between major airports and satellite airports. The third level is the Basic Backup Network, also defined by the FAA, which includes approximately 222 VOR/DMEs in US airspace (160 in CONUS). Additionally, a transition to a DME-only network will be analyzed. In alternatives where VOR and DME are used as redundant navigation, the effect of relaxed maintenance time requirements, which could reduce cost of maintenance, will be explored.

## **ILS**

Three levels of ILS are considered in various alternatives. The first level is the current system of Category I/II/III ILS, including projected growth over the study period. The second level is the Minimum Operational Network, as defined by the FAA, that includes approximately 419 Category I ILSs and 99 Category II/III ILSs. The third level is the Basic Backup Network, which includes approximately 332 Category I ILSs. In alternatives where ILS is used as a redundant landing system, the effect of relaxed maintenance time requirements, which could reduce cost of maintenance, will be explored.

## **Inertial Systems/Flight Management Systems (FMSs)**

In all alternatives, it is assumed that all new jet transports will be produced with inertial systems and FMS; some implementations of the inertial/FMS/GPS interface will allow increased navigation performance in the case of GPS outages.

The benefits of low-cost inertial systems in combination with GPS will also be investigated as a method to increase the robustness of GPS and GPS augmentation for General Aviation (GA) and other users. However, since no low-cost inertial systems exist, this evaluation will only be for future potential to reduce the dependency of ground based NAVAIDS for redundancy.

### **Loran C**

Loran C will be operated at least until 2008. The FAA will determine whether Loran-C standards, equipment, and procedures could be upgraded to provide NPA capability. If Loran-C is found to be a useful element of a future alternative, the FAA will also investigate if a Loran-C data broadcast capability would be useful. While the US government may decide to retain Loran C past 2008, this step will only be taken after analysis of the potential costs and benefits.

### **TACAN and NDB**

In all alternatives, TACAN will be maintained in accordance with DoD requirements, and NDB will be provided as long as user demand warrants.

#### 4. Description of Alternatives:

The four alternatives described below are summarized in the following table in terms of the services available to provide the operational capabilities.

##### Summary–Navigation Services

<i>Services</i>	<i>Alternative I</i>	<i>Alternative II</i>	<i>Alternative III</i>	<i>Alternative IV</i>
<b>RNAV (to support Free Flight objectives)</b>	GPS, DME/DME, VOR/DME, (Loran-C)	GPS/WAAS, DME/DME, VOR/DME, (Loran-C)	GPS/WAAS, DME/DME, VOR/DME, (Loran-C)	GPS/WAAS, DME/DME? VOR/DME? (Loran-C)
<b>Station/Heading Referenced Navigation</b>	VOR, DME, NDB	VOR, DME, NDB	VOR, DME, NDB	Redundant Capability
<b>IPV (vertical component)</b>	BARO VNAV	BARO VNAV	GPS/WAAS	GPS/WAAS
<b>Precision Approach</b>	a) ILS b) ILS, LAAS	a) ILS b) ILS, LAAS	a) ILS, WAAS b) LAAS, WAAS, ILS	WAAS & LAAS, ILS
<b>Expected User Equipage</b>	<i>Note 1</i>			
<b>Planned Decommissioning of ground NAVAIDs</b>	None			Most VORs, DMEs, ILSs

*Note 1: Free Flight operations will have to be able to handle cases where the RNAV capability is lost, particularly in high-traffic airspace. This is a particular limitation for Alternative I where a large number of aircraft may be using low-availability GPS to conduct Free Flight operations.*

The “Expected User Equipage” and “Planned Decommissioning of Ground NAVAIDs” rows are not filled in but are shown to illustrate that these need to be determined through coordination with the user community. The expected user equipage for each will need to be determined for each class of user (based on the operational capabilities desired and through collaboration with the user community) and consequent decommissioning of ground-based NAVAIDs will be determined accordingly.

## **Alternative I (No WAAS)**

### **Summary**

Alternative I provides no wide area augmentation for GPS. VORs and DMEs are maintained at their current levels plus growth. Precision approach capability (Category I/II/III) will be provided by retaining the current ILS system, or alternatively by LAAS with a redundant Category I ILS capability (both LAAS and no LAAS options will be investigated). If LAAS is chosen, a long-term decision to transition to an extended LAAS will be considered.

### **Government Services Provided**

The FAA will support area navigation by implementing Free Flight concepts for en route through terminal operations, which can use either a GPS, inertial, or VOR/DME-based area navigation system (RNAV). To permit approaches with a vertical descent profile, the FAA will develop IPV's for all instrument runways where terrain, obstacles, and airspace permit.

A VOR/DME network will be maintained to ensure required availability and continuity for navigation, including growth as required (including growth for BARO-VNAV approaches). As discussed earlier, Loran C and NDB will also be maintained.

Precision approach service (including Category I, II, and III) will be provided at the current level, plus growth, by ILS. Alternatively, precision approaches will be provided by LAAS, with a redundant capability provided by a Basic Backup or Minimum Operational Network of Category I ILSs.

### **Operational Capabilities**

#### **En Route through Nonprecision Approach Capabilities:**

Alternative I will provide satellite-based navigation for en route through nonprecision approach operations in the NAS with the availability of the basic GPS system with RAIM. This capability alone might be sufficient to provide the navigational support for Free Flight objectives, ADS-B, and the use of Terrain Avoidance Warning Systems (TAWS) applications, except possibly in high traffic airspace where the low availability could result in high controller and pilot workload. Most Free Flight objectives would be met by FMS-equipped aircraft, with VORs and DMEs available as redundant navigation aids for en route and nonprecision approaches, since many users, especially those without inertial systems, may have to revert to VOR/DME

operations during GPS outages (as much as 5 percent of the time, or approximately 400 total hours per year).<sup>4</sup>

Nonprecision and BARO IPV GPS approaches will be provided for all instrument runways, terrain and airspace permitting. Ground-based nonprecision approaches will remain available using VOR/DMEs and NDBs.

#### Precision Approach Capabilities:

Precision Category I/II/III approaches will be available at the 1998 level of service, plus projected growth, using ILS.

A sub-alternative that transitions to LAAS will also be investigated. If LAAS is implemented, then some ILSs will be retained for busy and international airports at a level of the Basic Backup or the Minimal Operational Network. LAAS systems would allow for improvements over the basic GPS and ILS, such as all-weather curved precision approaches and all-weather surface navigation, in addition to the capability of a precision approach to all instrument runways.

#### User Equipment

GPS for en route and nonprecision approach operations would be optional for Air Carrier operators with FMS/inertial installed. Air carrier aircraft could also use GPS in combination with inertial, possibly allowing a reduction in VOR/DME avionics requirements. Air Taxi and GA operators could either remain equipped for VOR/DME, or equip with GPS and VOR—depending on the level of capability desired for operations. DME and ADF would also be optional. Users who desire the capability of a vertically guided nonprecision approach without LAAS could install a digital altimeter or improved altitude encoder to use with GPS to provide an IPV.

For precision approaches if no LAAS is provided, all users desiring precision approach capability will need to be equipped with ILS. If LAAS is provided, air carriers could equip with LAAS avionics for operations in high-density airspace and on the airport surface, and would maintain ILS equipment as a redundant capability. Air Taxi and GA users desiring precision approach could also equip with ILS or LAAS.

---

<sup>4</sup> The FAA will need to determine if this low GPS availability would limit the use of Free Flight operations in high-traffic airspace to users with alternative RNAV capability (e.g., DME/DME, inertial) because of the high workload necessary to return to station-referenced procedures or use of radar vectors.

## **Alternative II (Simplified WAAS (No Precision Approach))**

### **Summary**

Alternative II involves a minimal implementation of WAAS providing a robust en route and nonprecision approach capability in the NAS, but not providing precision approach, except for BARO-VNAV IPVs. The improvement in WAAS capability over Alternative I may allow the decommissioning of many ground-based navigational aids while maintaining a reduced implementation of the WAAS system. Some VORs and DMEs would be maintained to provide redundancy and to ensure availability requirements are met. Precision approach capability (Category I/II/III) will be evaluated with the same options as Alternative I.

### **Government Services Provided**

In Alternative II, the FAA will provide radio navigation service for en route through NPA using a combination of a minimal-capability WAAS and reduced numbers of VORs and DMEs. Two levels of VOR/DME will be investigated: a Minimum Operational Network and a Basic Backup Network. WAAS will consist of Simplified WAAS (No Precision Approach). This will provide an improved availability of GPS over Alternative I levels, due to the improvements from the WAAS system. VOR, DME, and NDBs will be repaired and replaced using newly developed procedures that accommodate relaxed maintenance response time to reduce O&M costs.

Precision approach service (Category I, II, and III) will be provided in an identical manner to Alternative I (i.e., full ILS or LAAS with redundant ILSs).

### **Operational Capabilities**

#### **En Route through Nonprecision Approach Capabilities:**

Alternative II will provide satellite-based navigation for en route through nonprecision approach operations in the NAS with higher availability than the basic GPS system used in Alternative I; this configuration will improve the navigational support of Free Flight objectives and ADS-B and the use of GPS for TAWS applications over Alternative I, particularly for operations in high-traffic airspace. This availability improvement is mainly a benefit for non-inertial equipped aircraft since inertial equipped aircraft could already achieve high availability. Some VORs and DMEs will be available as redundant navigation aids for en route and nonprecision approaches, which would be needed by non-inertial users less than approximately 1 percent of the time, or approximately 1 hour per year.

As in Alternative I, nonprecision and IPV GPS approaches will be provided for all instrument runways, terrain and airspace permitting, but Alternative II will have

additional availability because of the WAAS component, which will be useful for users without inertial equipage. Ground-based nonprecision approaches will remain available using VOR/DMEs and NDBs, although at a reduced number than Alternative I.

#### **Precision Approach Capabilities:**

Similar to Alternative I, Precision Category I/II/III approaches will be available at the 1998 level of service, plus growth, using ILS.

An alternative that transitions to LAAS will also be investigated. If LAAS is installed, then some ILSs will be retained for busy airports at a level of the Basic Backup or the Minimal Operational Network. LAAS systems would allow for improvements over the basic ILS and VOR/DME structure in Alternative I. These would include such capabilities as all-weather curved precision approaches and all-weather surface navigation, in addition to the capability of a precision approach to all airport runways.

#### **User Equipment**

User equipment will be identical to Alternative I, except that inertial users may be able to reduce VOR avionics if equipped with WAAS or LAAS avionics.

### **Alternative III (Simplified WAAS (With Precision Approach))**

#### **Summary**

Alternative III is centered around a more extensive implementation of WAAS than Alternative II—Simplified WAAS (Without Precision Approach). This implementation will provide en route and nonprecision approach capability in the NAS, and will also provide precision approach at most places in the NAS to Category I or near-Category I minima. IPV approaches will also be provided, using WAAS vertical guidance rather than BARO VNAV.

The addition of precision approach service via WAAS should also allow the decommissioning of some additional ground-based navigational aids while maintaining a somewhat reduced implementation of the WAAS system (as compared to the Full WAAS system). As in Alternative II, some VORs and DMEs would be maintained to provide redundancy and to insure availability requirements are met. Precision approach capability (Category I/II/III) will be evaluated with the same options as Alternatives I and II, since Category I precision approach capability provided by WAAS will have a somewhat reduced availability in many geographic areas.

#### **Government Services Provided**

In Alternative III, the FAA will provide radio navigation service for en route through precision approach using Simplified WAAS (With Precision Approach).

VOR, DME, and NDBs will be repaired and replaced using newly developed procedures that accommodate relaxed maintenance response time in to reduce O&M costs.

An IPV approach service will be provided by using WAAS vertical guidance, along with limited Category I precision approach capability. Category I/II/III precision approach service will be provided by ILS. Alternatively, LAAS will provide Category I/II/III precision approaches, with ILS retained as a redundant system at the level of the Minimum Operational Network or the Basic Backup Network.

#### **Operational Capabilities**

En Route through Nonprecision Approach Capabilities:

Alternative III will provide similar satellite-based navigation service for en route through nonprecision approach operations in the NAS as provided by Alternative II. This will offer the same availability improvement as did Alternative II over Alternative I for navigational support of Free Flight objectives and ADS-B and the use of GPS for TAWS. Some VORs and DMEs will remain as redundant navigation

aids for en route and nonprecision approaches. Two levels of VOR/DME will be investigated: a Minimum Operational Network and a Basic Backup Network.

As in Alternative II, nonprecision and IPV GPS approaches will be provided for all instrument runways, terrain and airspace permitting, with the same availability benefit over Alternative I. Ground-based nonprecision approaches will remain available using VOR/DMEs and NDBs, although at a reduced number than for Alternative I.

#### **Precision Approach Capabilities:**

IPV precision approaches using WAAS vertical guidance will be provided by WAAS at most places in the NAS, allowing curved approaches and some surface navigation capability. ILS will be maintained for Category I/II/III.

An alternative that transitions to LAAS will also be investigated. However, even if LAAS is installed, some ILSs will be retained for busy airports at a level of the Basic Backup or the Minimal Operational Network. LAAS systems would allow for improvements over the basic ILS and VOR/DME structure in Alternative II, such as all-weather curved precision approaches and all-weather surface navigation. LAAS would also provide precision approach to all airport runways with higher availability than provided by WAAS.

#### **User Equipment**

User equipment will be similar to Alternative II, except that many users (especially GA) may rely mainly on WAAS for IPV (without the expense of an enhanced barometric altimeter or encoder) and precision approach and might opt to delete ILS avionics.

## **Alternative IV (Full WAAS)**

### **Summary**

Alternative IV is the most extensive implementation of WAAS, using Full WAAS; this implementation will provide a robust en route and nonprecision approach capability in the NAS, and will provide Category I precision approach at most places in the NAS with high availability. IPV approaches will also be provided.

The improvement in WAAS capability over Alternative III should also allow the decommissioning of some additional ground-based navigational aids. As in Alternative III, some VORs and DMEs would be maintained to provide redundancy. Precision approach capability (Category I/II/III) will be evaluated with the same options as Alternative III.

### **Government Services Provided**

In Alternative IV, the FAA will provide a more robust radio navigation service for en route through NPA using Full WAAS. This will provide an improved availability of GPS over Alternative III levels for en route through Category I precision approach.

VOR, DME, and NDBs will be repaired and replaced using newly developed procedures that accommodate increased maintenance response time in order to reduce O&M costs.

Similar to Alternative III, Category I precision approach service will be provided by WAAS, with some ILS retained as a redundant capability (especially at busy airports), at the level of the Minimum Operational Network or the Basic Backup Network. Category II/III precision approach will be provided by ILS. Alternatively, LAAS will provide Category I/II/III precision approaches, with ILS retained as a redundant system at the level of the Minimum Operational Network or the Basic Backup Network.

### **Operational Capabilities**

#### **En Route through Nonprecision Approach Capabilities:**

Alternative IV will provide a robust satellite-based navigation for en route through nonprecision approach operations in the NAS as Alternatives II and III. Some VORs and DMEs will remain available as redundant navigation aids for en route and nonprecision approaches; non-inertial users would revert to VOR/DME operations only for rare events, such as widespread GPS jamming. Three levels of VOR/DME will be investigated: a Minimum Operational Network, a Basic Backup Network, and no ground-based backup.

As in Alternative III, nonprecision and IPV GPS approaches will be provided for all instrument runways, terrain and airspace permitting, but Alternative IV will have additional availability over Alternatives II and III. Ground-based nonprecision approaches will remain available using VOR/DMEs and NDBs, although at a reduced number than Alternatives I-III.

#### Precision Approach Capabilities:

Precision Category I approaches will be provided by WAAS at most places in the NAS. Some ILS will be maintained for Category I at busy airports and for Category II/III at the level of the Basic Backup Network or the Minimum Operational Network, but an alternative that maintains no ground-based precision approach backup will also be investigated.

An alternative that transitions to LAAS will also be investigated. If LAAS is installed, then some ILSs will be retained for busy airports at a level of the Basic Backup or the Minimal Operational Network. LAAS systems would allow for improvements over the basic ILS, such as all-weather curved precision approaches and all-weather surface navigation, in addition to the capability of a precision approach to all airport runways.

#### **User Equipment**

User equipment will be similar to Alternative III, although the Full WAAS may allow users to remove VOR, DME, and ILS avionics, depending on the level of redundancy desired.